

Results of Experimental Dark Halo Crater Studies: Implications for Lunar Cryptomare Thickness Measurements; I. Antonenko,¹ M.J. Cintala², J.W. Head,¹

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Summary: Our desire to study cryptomaria through analysis of dark-halo craters has prompted an experimental program to refine our understanding of the conditions of their formation. To this end, a series of impacts into layered sand targets was performed to determine mare (d_m) and highland substrate (d_h) penetration required to form or obscure a dark halo. Analysis of the results yields the relations $d_m = 0.21d_e$ and $d_h = 0.34d_e$ where d_e is the depth of excavation. Caution must be used in applying these values, since our target materials do not simulate the spectral characteristics of the Moon.

Background: Dark halo impact craters (DHC's) provide evidence for buried mare materials [1,2] and, under suitable conditions, can be used to estimate the thicknesses of such cryptomare deposits. In any given area, the smallest observed DHC should define the top of the cryptomare, and therefore the thickness of the overlying, obscuring ejecta, while the largest observed DHC should define a minimum estimate of the bottom of the mare layer. The difference between the mare base and the overlying ejecta provides an estimate of the cryptomare thickness [3].

The determination of these thicknesses, however, is a complex process (Fig. 1 and 2). First the depth of the transient crater (d_T) must be obtained. This can be determined by measuring the rim-to-rim diameter of the crater (D_T), then converting this diameter to the transient rim-to-rim diameter (D_{TC}) and the transient rim-to-floor depth (d_T) [4]. From this value, the depth of excavation (d_e) from the pre-impact surface is determined using the relation $d_e = 0.33d_T$ [5], giving a first order approximation of the thickness of the overlying deposits. This approach has been applied to our study area on the western limb of the Moon, where the d_e values of minimum DHC's were found to be generally consistent with theoretical predictions [6] for ejecta from Orientale, and cryptomare thicknesses were estimated to be on average 900 m [7].

Another factor, however, must be considered. Figure 1 illustrates how some penetration into the mare layer (d_m) is required before a dark halo becomes visible. This value d_m will affect estimates of the ejecta thickness for the smallest DHC's. Similarly, some penetration into the highland substrate (d_h) is required before sufficient highland material is ejected to obscure a dark halo. This value d_h will affect estimates of mare depth for the largest DHC's, assuming they are tapping the bottom of the cryptomare. The magnitude

of these two values is not known. We therefore began a series of experiments to simulate dark halo formation, in order to determine the values of d_m and d_h .

Experiments: Layered targets of dyed, resin-coated sand were prepared to simulate lunar stratigraphy. These targets were impacted at velocities of 1, 1.5 and 2 km/s, using spherical projectiles, 6.35 mm in diameter; most projectiles were glass, but aluminum and nylon spheres were also used. After the impact event, the targets were baked to solidify them and then sawed in half, allowing for accurate measurements of subsurface features (Fig. 2).

The experiments were conducted in three phases. In the first phase, a light-colored layer over a dark layer was used to study the formation of simple, dark halos. The thickness of the light top layer was varied for each velocity until the underlying dark layer was excavated in sufficient quantities to produce a barely visible dark halo. A barely visible DHC was defined by the presence of a tenuous, but relatively symmetrical, halo of material from the dark layer around the experimental crater, identified by visual inspection. Spectral measurements of some of the craters were also taken, using the portable spectrometer MINI. These measurements show that, the definitions of spectral and visible detectability coincide in these experiments [8].

In the second phase, we simulated dark halo obscuration by impacting targets in which a layer of dark material was sandwiched between two layers of light material. The thicknesses of the top light layer and the dark layer were varied in order to permit ejection of sufficient quantities of the lower light layer to obscure the dark halo. Only glass projectiles were used in this series. Physical constraints on the maximum size of the crater we could produce and the minimum layer thickness that could be constructed prevented us from completely obscuring the dark halo.

In the third phase, we attempted to improve our analogy to the Moon by replacing the top light layer with a layer of mixed light and dark material. The thickness of this mixed layer was then varied until the underlying pure dark layer was excavated in sufficient quantities to produce a visible DHC. Again, the presence of a DHC was identified by visual inspection, and only glass projectiles were used.

Results: We identified three different types of craters in phase 1; DHC's with well-developed symmetrical halos of dark material, minimum DHC's with tenuous dark halos, and incipient DHC's with no visible halo but emergent excavation of dark material. The ratio of the top layer thickness divided by the crater

depth (t/d_r) is plotted in Fig. 3 for these craters as a function of crater type and projectile. As expected, incipient craters generally have higher t/d_r ratios, DHC's have lower t/d_r ratios, and minimum DHC's have intermediate ratios. Trends apparently due to projectile density can be seen, with the denser aluminum producing generally higher t/d_r ratios and lighter nylon lower ratios relative to the glass projectiles.

For Incipient DHC's, the t/d_r ratio represents the excavation depth/depth (d_e/d_r). Taking an average of this ratio for all Incipient DHC's produced by glass projectiles gives a value of 0.324, very close to the value of 0.33 from [5]. Thus we can be confident in our assessments. Taking the average for all glass produced Minimum DHC's gives layer thickness/crater depth (t/d_r) to be 0.255 ($t = 0.26d_r$). Considering that $d_m = d_e - t$, we can see that $d_m = 0.07d_r$ or $d_m = 0.21d_e$, for glass projectiles. Variations in projectile density may affect these values by no more than $\pm 5\%$. Variations in velocity may also have a small affect on these values at the velocity range we considered.

As was mentioned above, we did not achieve a complete obscuration of a dark halo in phase 2 of our experiments. However, we did observe four craters with distinct light halos. These can provide a lower bound for the value of d_h . The average t/d_r value for these craters is 0.216. By analogy with d_m we calculate that $d_h = 0.11d_r$ or $d_h = 0.34d_e$ at the very least.

The results of our phase 3 experiments showed only incipient and minimum DHC's. For incipient DHC's, a thickness of less than d_e was found for top layers with more than a 10% dark component in the mixture. This is most likely due to the difficulty of identifying a small number of excavated dark grains on a background that itself contains dark material. Only 3 minimum DHC's were produced in this phase. The value of d_m appears to vary a little in response to the composition of the top layer, however, more work is needed before these findings can be confirmed.

Application: Our experiments show that d_m and d_h are very important parameters to consider when applying this technique to estimates of cryptomare thicknesses. When the results of this experimentation are applied to our study area on the western limb of the Moon, the resulting average cryptomare thickness is found to be 550m, a decrease of 39% from our original 900m estimate. It must be noted, however, that our experimental conditions were not intended to simulate the spectral properties of the Moon. The albedo contrast and grain size-to-crater ratio of our materials is much greater, potentially affecting the detection threshold of our DHC's and thus the value of d_m and d_h [8]. Further work is needed to resolve the extent of such an effect.

References: [1] P. Schultz & P. Spudis, *PLPSC* 10, 2899, 1979; J. Bell & B. Hawke, *PLPSC* 12, 665, 1981. [2] I. Antonenko *et al.*, *EMP*, 69,141,1995. [3] I. Antonenko & J. Head, *LPSC* 25, 35, 1994; I. Antonenko & J. Head, *LPSC* 26, 47, 1995. [4] J.H. Melosh *Impact Cratering: A Geologic Process*, 1989. [5] D. Stöffler *et al.*, *JGR*, 80, 4062, 1975. [6] T. McGetchin *et al.*, *EPSL*, 20, 226,1973; P. Schultz *et al.*, *PLPSC* 12, 181, 1981. [7] Antonenko and Head, *in preparation*. [8] I. Antonenko *et al.*, *LPSC* 27, 31, 1995.

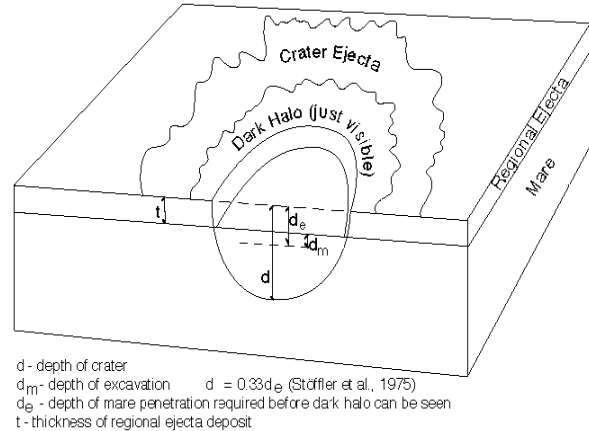


Fig. 1. Block diagram showing the relationship between crater depth (d), depth of excavation (d_e) and depth of mare penetration (d_m) for a minimum DHC.

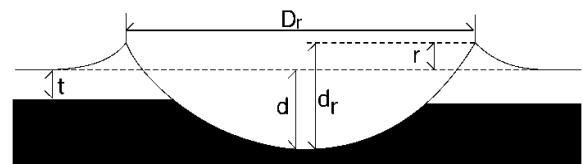


Fig. 2. Diagram illustrating the relationship between the measured variables for our experiments.

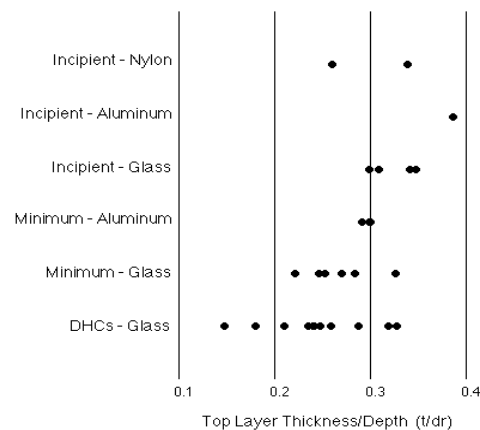


Fig. 3. Plot of the top layer thickness divided by the crater depth (t/d_r) for simple, dark-halo craters as a function of crater type and projectile composition.